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ECO-DESIGN OF BUILDINGS AND COMPARISON OF MATERIALS

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ABSTRACT

Sustainable building integrates many issues, for instance: reducing energy consumption while keeping a high level of thermal comfort (in winter as well as in summer conditions), global environmental problems such as global warming or ozone depletion, indoor air quality issues, relevant material resource and waste management. Such issues are highly related to the choice of building materials. Eco-design requires therefore a relevant integrated assessment for the building materials not only at the process stage but over the whole life cycle of the buildings including the dominant use phase. Life Cycle Assessment (LCA) applied to buildings is enlarging the scope of material assessment.

An innovative approach, EQUER (Evaluation of environmental quality of buildings), has been developed at Ecole des Mines for architects and consultants by linking a life cycle simulation tool with a building thermal simulation. The life cycle inventory database Ecoinvent is used to evaluate the environmental impacts of material fabrication and other processes (energy, transport,...).

There are still many uncertainties and limits to the present state of the art of LCA. The uncertainties concern both the data (inventories) and impact indicators. For instance, the global warming potential (GWP) of other gases than CO₂ is known with a high rate of uncertainty. Global indicators related to human or eco-toxicity are doubtful because the location of the emissions is not considered: in fact air pollution inside buildings do have a much larger effect than diluted external emissions and no indoor indicator has yet been elaborated. Also, the processes occurring at the end of the building life cycle are difficult to foresee, particularly because buildings are generally long lasting (though it may be assumed that mixing materials -concrete with polystyrene or wood for instance- will make the future waste management more difficult).

Despite these limits, an attempt to convert these inventories data into a meaningful environmental profile is proposed in order to perform sensitivity studies for different building materials and derive environmental material performance according to a specific building use. We propose here a contribution concerning the evaluation of quantifiable environmental impacts of buildings for different material choices and end of life scenarios.

The output of the software is an eco-profile including the different CML indicators (global warming, acidification, eutrophication potentials, smog, etc.), IMPACT2002⁺ indicators (human toxicity and ecosystem quality) plus some aggregated values like primary energy and water consumption, generation of radioactive and other waste. These indicators are given either for the different phases or for different alternatives or projects.

The methodology is presented and illustrated by a comparative study on a single family house, concerning the comparison of three structural materials: concrete blocks, bricks, and timber. The results of this exercise are presented and its limits are discussed.

INTRODUCTION

The building sector is the first energy consuming sector in Europe, with around 40% of the overall consumption [1] and represents a major source of CO₂ emissions, use of resources and waste generation. Focusing on relevant material choices is essential and requires appropriate tools.

Seven European building LCA tools have been analysed and compared in the frame of the Presco European thematic network [2]. One of the case studies considered in this inter-comparison exercise was a Swiss house (Futura). The results of the tools regarding greenhouse gases emissions were consistent (around +/- 10% between the tools).

One of these tools, EQUER [3], is linked with the thermal simulation tool COMFIE [4] and its user friendly interface PLEIADES. The present paper reports the results obtained for the same Futura house using new LCI data from the Swiss base Ecoinvent 1.2 [5], and a new set of environmental indicators (see table 2 below).

The Futura house is a single family house with two levels (210 m² heated area), well insulated, with a high solar aperture. The energy for space heating and domestic hot water is gas, and the heating demand corresponds to a Swiss climate. The European electricity mix is considered. The cycle assessment has been considered over an 80 years operation period.

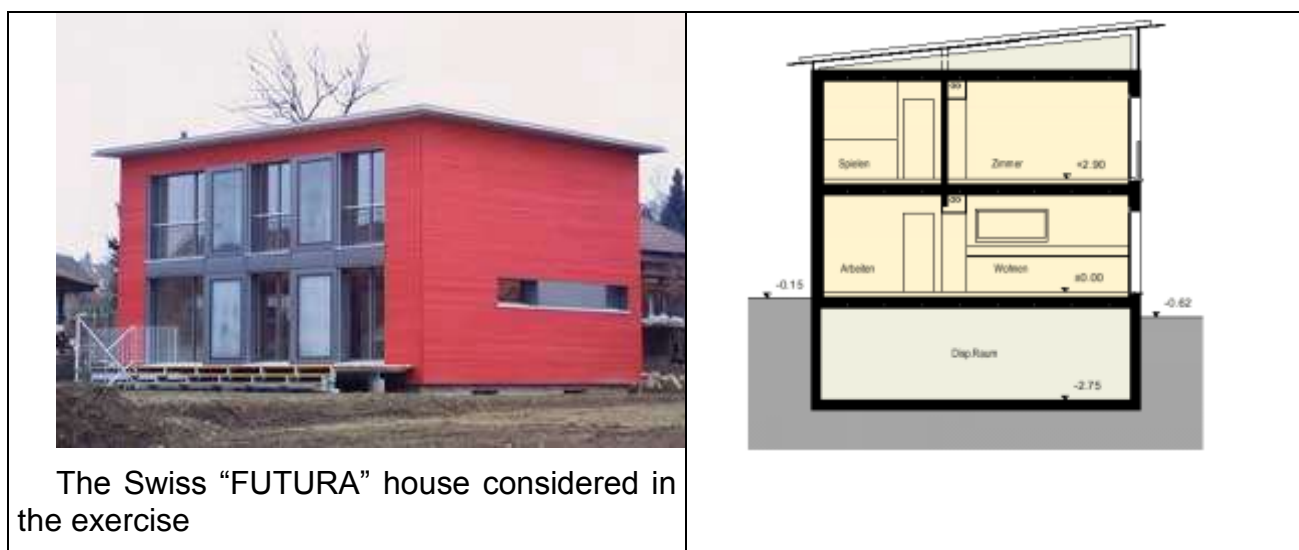


Figure 1: The Futura House

The user friendly Pleiades tool enables to import architects plans and convert them into a model suitable for energy simulation and LCA, see figure 2.

Blanc, I., Peuportier, B., "Eco-design of buildings and comparison of materials", *In Proceedings of the 1st international seminar on Society & materials, SAM1*, [CD ROM], 6-7 mars 2007, Séville, Spain, European Commission, Directorate General, Joint Research Center.

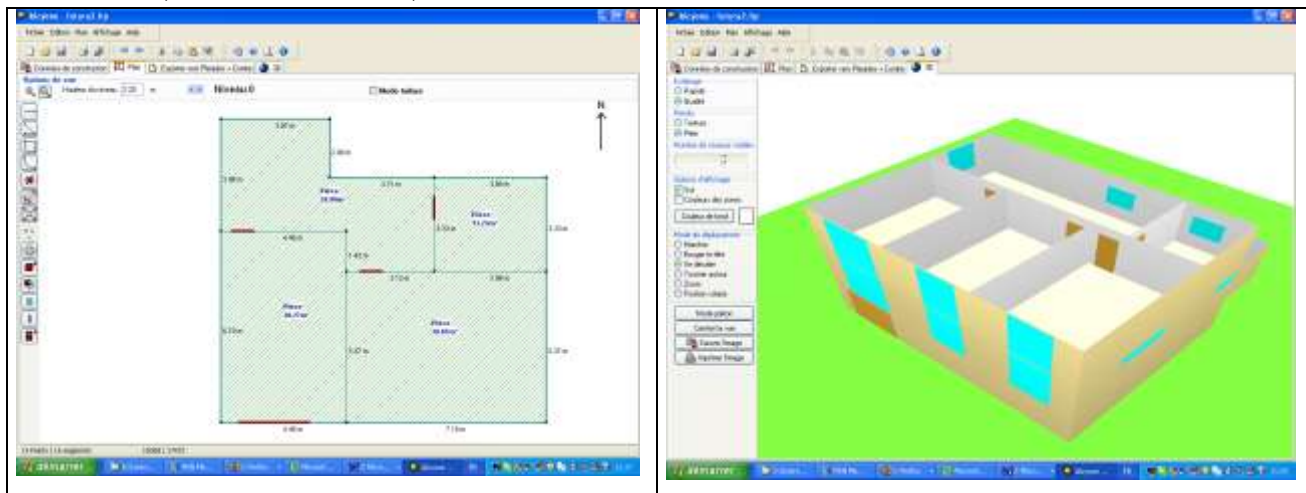


Figure 2: Model of the Futura House

Four alternatives are now studied (See table 1). They differ with the composition of the outside walls: one option being in brick, the second one in concrete and the third one in wood. An additional option is also studied and takes after the passive concept with heat recovery for the ventilation air scheme.

Parameters	Brick option	Concrete option	Wood option
Wall composition	18 cm Brick + 17 cm external glass wool	18 cm Concrete block + 17 cm external glass wool	Wooden frame with 16 cm glass wool insulation
Roof composition	16 cm of glass wool insulation	16 cm of glass wool insulation	16 cm of glass wool insulation
Slab composition	5 cm anhydrique slab upon 9 cm insulation and 20 cm concrete slab	5 cm anhydrique slab upon 9 cm insulation and 20 cm concrete slab	5 cm anhydrique slab upon 9 cm insulation and 20 cm concrete slab
Glazing type	Low emissivity , argon double glazing - Wood frame	Low emissivity , argon double glazing - Wood frame	Low emissivity , argon double glazing - Wood frame

Table 1 : Main characteristics of the three alternatives

The life Cycle of the building is divided in four principal phases: construction, operation, renovation and end of life.

Construction phase assumptions

- 50 km transport distance between material production and building site (this value can be easily modified by the user of the software);
- 5% materials produced in supplement and not used on the building site;
- 20 km transport for waste (=5% of useful materials);
- calculation of the volumes based on internal areas, thus corners are neglected;

Operation phase assumptions

Gas energy is used, both for heating and hot water production. The equipment efficiency is 80% for space heating and for domestic hot water.

The water consumption is 49 liters hot water and 100 l cold water per person and per day. The production of drinking water is also accounted for, as well as waste water treatment. An 80% efficiency is considered for the drinking water distribution network.

The electricity consumption is around 16 GJ per year (4 400 kWh). The European electricity mix is considered : 37% nuclear, 28% coal, 15% hydro, 10% oil and 10% natural gas. The operation related impacts are calculated over 80 years. Using COMFIE, the dynamic simulation tool, heating load are assessed (Figure 3).

- Internal temperature 21°C (constant);
- The weather data of Macon (France) are used and the temperature is corrected for Biel altitude, 434 m;
- External ventilation constant 0.6 ach (air change per hour);
- 4 persons living in the building, with a constant occupancy;
- 85% of the electricity consumption is considered as internal gain : 15% is used e.g. to heat water in a washing machine etc. and do not contribute in internal heat gains (the hot water is sent to the sewage without heating the house).



Figure 3: Yearly heating consumption for all scenarios

The passive house standard corresponds to 15 kWh/m² yearly heating consumption. The alternative that we defined here, just by adding heat recovery on ventilation air, is approaching this performance (18 kWh/m²). Increasing the insulation thickness and triple glazing would have increased the performances.

Renovation

Windows are assumed to be changed every 30 years. No wall painting and floor covering is considered in the exercise, otherwise a duration would have been assumed for these components. The LCA tool accounts for impacts related to the end of life of components and their replacement by identical objects.

End of life assumptions

- Incineration of wood and plastics as well as wooden windows is considered.
- Land filling for concrete, plaster and mineral insulation.
- Recycling of metals.
- 20 km transport between the house and land filling or incineration sites, 100 km to recycling site

LIFE CYCLE ASSESSMENT

Ecoinvent 1.2 LCI database [5] has been used for the fabrication of buildings materials and other processes (Electricity production, gas heating in a boiler, potable water production etc.).

Impact indicators are calculated according to table 2. The primary energy indicator is based upon the upper heating value for fuels (the "cumulative energy demand" defined in [5] is used).

Environmental theme	expressed by	Profile name	Reference	unit
Primary Energy	absolute value	ENERGY	[5]	GJ
water consumption	absolute value	WATER	-	m ³
depletion of abiotic resources	absolute value	RESOURCES	[6]	kg Sb equivalent
waste creation	absolute value	WASTE	-	tons
radioactive waste creation	absolute value	RAD-WASTE	-	dm ³
global warming	potential	GWP100	[7]	ton CO ₂ equivalent
acidification	potential	ACIDIFICATION	[6]	kg SO ₂ equivalent
eutrophication	potential	EUTROPHICATION.	[6]	kg PO ₄ ³⁻ equivalent
ecotoxicity	potential	ECOTOX-W	[8,9]	PDF·m ² ·year
human toxicity	potential	HUMAN-TOX	[8,9]	DALY
photochemical oxidant formation	potential	O ₃ -SMOG	[6]	kg C ₂ H ₄ equivalent

Table 2: Environmental themes considered

DISCUSSION OF THE RESULTS

The four options are now compared over the building life time (see Figure 4). These results illustrate the importance of the use phase over the global performance of a building during its life time in terms of energy efficiency and greenhouse gases emissions.

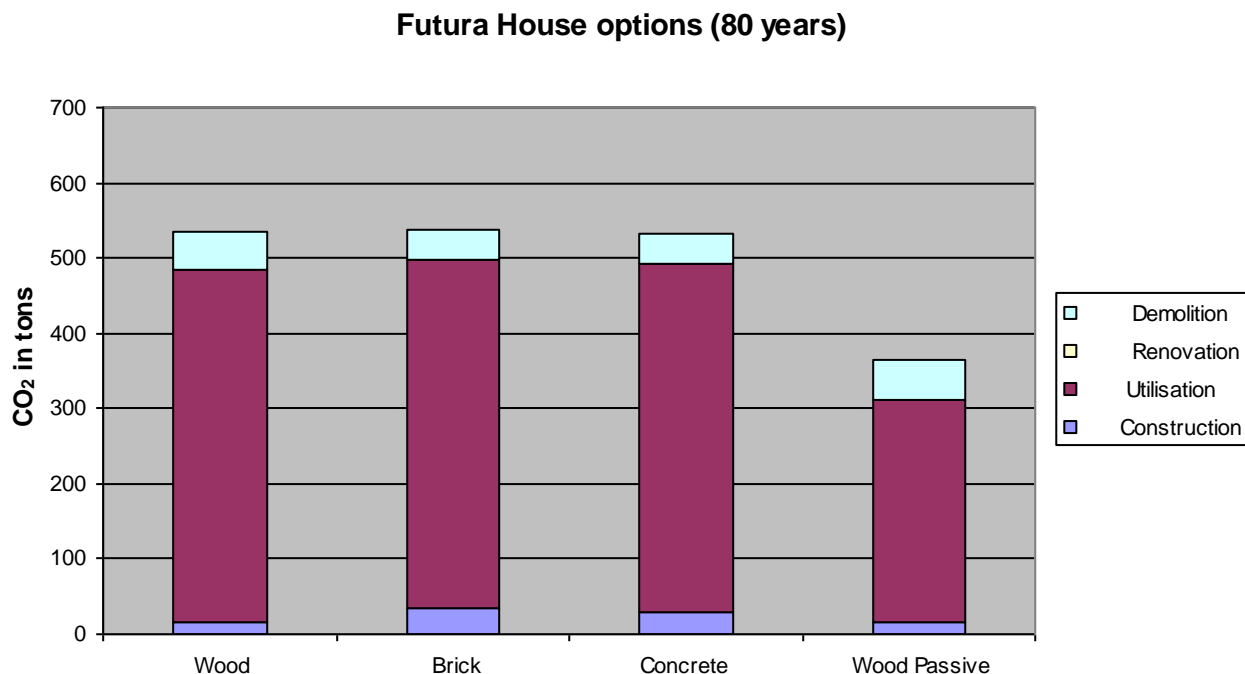


Figure 4: Greenhouse gas emissions

No significant difference are to be found for the global CO₂ balance between the first three options. The only significant difference is to be found with the "passive" building option. This option relies upon heat recovery for air ventilation and such difference was already identified at the utilization phase (See Figure 3). A reduction of nearly a third of the equivalent CO₂ mass can be expected compared to standard buildings which is equivalent to 172 ton eq-CO₂ over the building life or a reduction of 0.5 ton/year/habitant. This result takes into account the additional building equipment for the ventilation system. If compared to 8,7 ton eq-CO₂ emitted by the average French habitant it represents over 6% of the total greenhouse gas.

Results for the 4 alternatives are now expressed for all impact indicators on Figure 5. The "brick" alternative is set as the reference on the graph. As already identified, the "Passive" wood option is minimizing the energy consumption by 30% as well as the greenhouse gases and resources depletion. All other indicators are quite close between the options.

Figure 5 : Environmental impacts of the 4 alternatives

Limits for the tool and perspectives for improvement

LCI data is missing for some components like heat exchangers and ducts in ventilation systems, but the related impacts are assumed to be small. LCI data generally correspond to European averages (e.g. European plastic industry) so that possible environmental efforts of a specific manufacturer is not rewarded.

The inter-comparison exercise has shown that half of the tools consider a zero CO₂ balance for biogenic CO₂, assuming that the CO₂ stored during photosynthesis is emitted again at the end of life. The other half accounts for a CO₂ storage, and makes a distinction between different end of life processes (e.g. incineration with or without heat recovery, land filling, recycling...). Harmonisation would therefore be needed.

In EQUER, the Heating Value of wood, plastics and other combustible materials is included in their embodied energy. An alternative is to consider that some types of timber are not used as fuel in practice. Here also harmonisation would be needed.

Improvement could be achieved by using statistical LCA approach, particularly regarding impacts occurring in a far future like end of life processes.

Taking advantage of this software package innovative features and modularity, sensitivity studies on key design parameters could be conducted: insulation thickness, thermal mass, orientation, end of life strategies. Such studies would allow key parameters to be identified, and possible simplification of LCA to be derived, easing the use of LCA in the design practice. Linking LCA and thermal simulation allows both thermal comfort and environmental performance to be evaluated : the functional unit corresponding to a building can therefore be defined in a more precise way.

Although no major differences have been established for the three options (Brick/Concrete/Wood) in this example, differences between building materials would be more significant when considering larger buildings (office buildings for example) due to the importance of the structure (in steel or concrete for example).

Recommendations for the Building sector in terms of investment and strategy related to building materials are possible thanks to Life Cycle Assessment. LCA does provide valuable knowledge when coupled to dynamic energy assessment : for systems with such long life time like buildings, energy related issues play an important role. Buildings heating load (and possibly cooling load) is highly dependent on climate parameters and its evaluation requires refined tools able to take into account material properties such as thermal mass. A systemic buildings analysis is needed to assess environmental performances in relation to a functional unit. Such functional unit has to be defined in order to provide a comfortable indoor climate with the lowest environmental impacts.

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